PROCEEDINGS OF SCIENCE

Particle Identification at PANDA

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for the PANDA collaboration

The PANDA experiment at the new Facility for Antiproton and Ion Research in Europe at GSI, Darmstadt, will study fundamental questions of hadron physics and QCD using high-intensity cooled antiproton beams with momenta between 1.5 GeV/c and 15 GeV/c. Efficient Particle Identification (PID) for a wide momentum range and the full solid angle is required for reconstructing the various physics channels of the PANDA program. Hadronic PID will be provided by sub-systems using Cherenkov light, time-of-flight, and dE/dx measurements. Electromagnetic calorimeters will identify electrons and photons while muons will be detected by a muon range system.
This contribution will give an overview of the PANDA-PID systems with an emphasis on the barrel and endcap DIRC counters and the SciTil (Scintillating Tile) system.

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1. Introduction

The Facility for Antiproton and Ion Research in Europe (*FAIR*) is currently under construction at GSI in Darmstadt, Germany. It will take a leading role in research in nuclear and hadron physics, nuclear structure, nuclear matter, studies with antiprotons, atomic and plasma physics, and several topics in applied science and accelerator development [1].

The GSI accelerators and a newly built proton-linac will be used as injectors for the FAIR accelerators and storage rings (Fig. 1). The PANDA experiment (Anti**P**roton **An**nihilation at **Da**rmstadt) uses cooled antiprotons at beam momenta between 1.5 GeV/c and 15 GeV/c. Protons are accelerated to 29 GeV/c until they hit a nickel target where antiprotons of 3.1 GeV/c are selected with an efficiency of about 10^{-5}. The antiprotons are then precooled and accumulated in the subsequent **C**ollector **R**ing (CR), and injected into the **H**igh **E**nergy **S**torage **R**ing (HESR) to get accelerated, stored, and further cooled. PANDA uses hydrogen pellet or cluster jet targets, or targets with heavier elements.

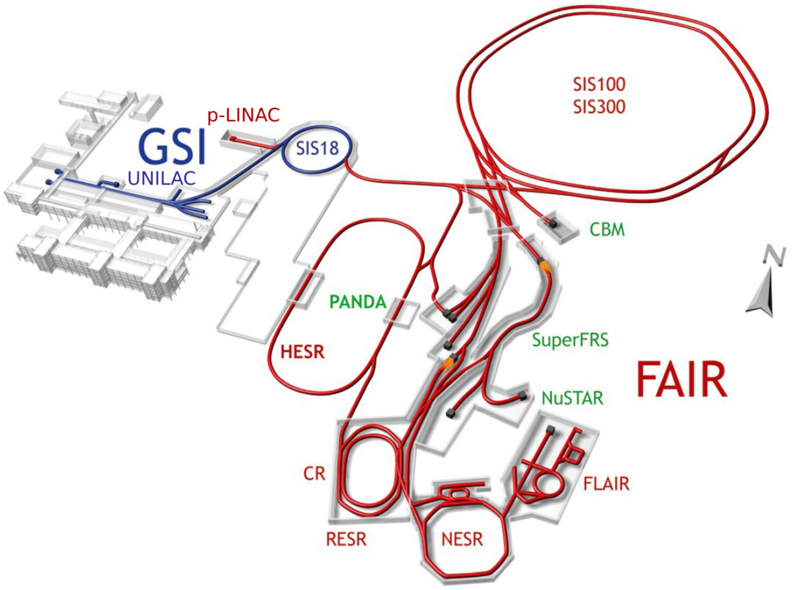


Figure 1: Layout of the FAIR facility (full version). In blue the existing GSI beam infrastructure.

PANDA adresses a wide range of physical fields. The experimental program covers high precision charmonium spectroscopy, in-medium properties of open and hidden charm, search for glueballs and exotics, hypernuclei, and time-like nucleon form factors. Many of these fields require excellent particle identification. As a hadron machine PANDA has to deal especially with a strong pion background which makes good pion kaon separation over a high angular and momentum range mandatory.

2. Particle Identification

2.1 Overview

The PANDA detector, shown in Figure 2, consists of the target spectrometer surrounding the

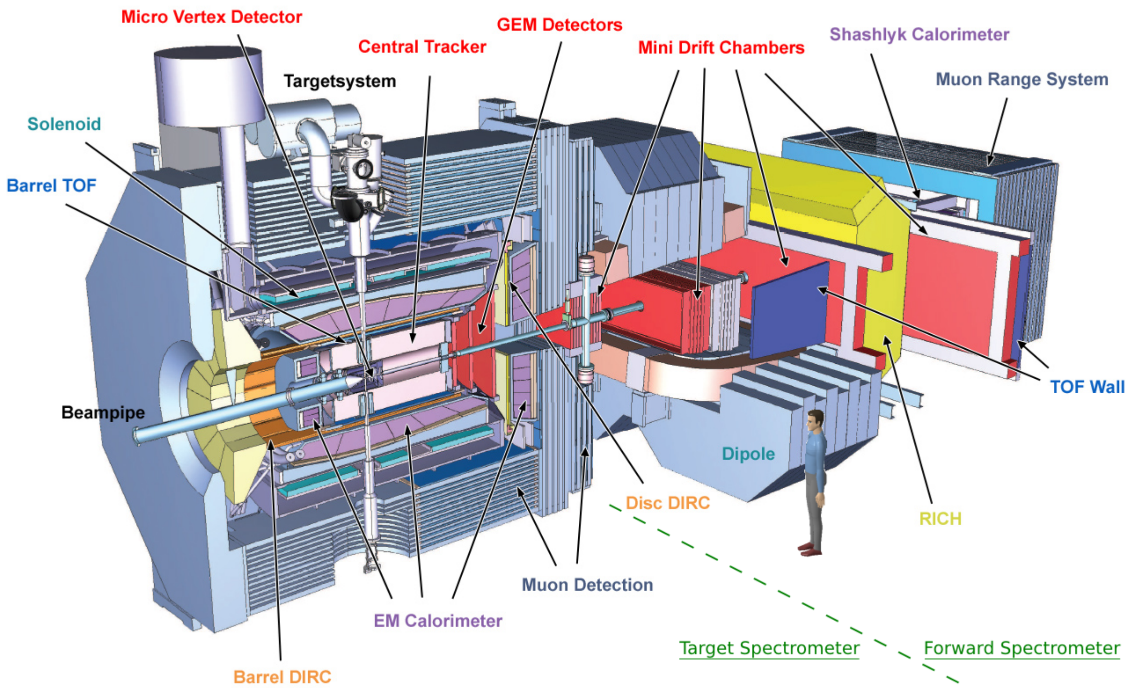


Figure 2: Schematic view of the PANDA detector.

interaction point and the forward spectrometer in downstream direction. In both parts several systems perform particle indentification (PID), some of them exclusively. A *micro vertex detector*, as central component around the interaction point with a outer radius of 13 cm, detects secondary vertices from D and hyperon decays with a spatial resolution better than 100 μm. In addition it is capable of charged particle identification via measuring dE/dx. It contributes to the global PID decision up to a momentum of 500 MeV/c for kaons and 1 GeV/c for protons [2].

The outer tracking system, the *straw tube tracker*, is designed as a barrel around the micro vertex detector. It consists of aluminized mylar tubes and has an outer radius of 42 cm from the beam axis. Its main task is the precise spatial reconstruction of the trajectories of charged particles in order to determine the momenta in the range from about a few 100 MeV/c up to 8 GeV/c. It also measures the specific energy-loss to separate protons, kaons, and pions in the momentum region below about 1 GeV/c [3].

Around the straw tube tracker a compact RICH type detector called *Barrel DIRC* (**D**etection of **I**nternally **R**eflected **C**herenkov light) [4] is placed as main component for hadronic PID in the barrel section of PANDA. It uses synthetic fused silica bars as Cherenkov radiators to provide a pion - kaon (and proton) separation for particle momenta up to 3.5 GeV/c at polar track angles between 22° and 140°. Another DIRC with disk-shape (Disk DIRC) is placed in the forward endcap of the target spectrometer. Pions and kaons with momenta up to 4 GeV/c and with polar track angles below the acceptance of the barrel DIRC down to 10° in horizontal and 5° in vertical direction are identified here.

A Time of Flight system called *SciTil* (**Sci**ntillating **Til**es) outside the Barrel DIRC, with a time resolution better than 100 ps, can be used for the identification of slower charged particles which do not emit Cherenkov light in the DIRC. Its barrel shape follows the geometrical shape of the Barrel DIRC. The main purpose of the SciTil is to aid the global event building process of PANDA.

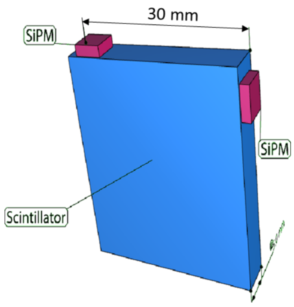
Electromagnetic calorimeters (EMC) identify and absorb e^+, e^-, and γ. They surround the Barrel DIRC and cover the forward and the backward endcap. Lead tungstate crystals are used as fast and radiation hard scintillators to deliver a good energy measurement for electromagnetic particles from a few MeV to 10 GeV in the limited space of the target spectrometer.

Muons are identified at the outermost part of the detector as they pass the inner systems without major interactions. A *muon range system* is instrumented within the yoke of the PANDA solenoid so that alternating layers of absorbing iron and detection material can determine the energy of the passing or absorbed muons.

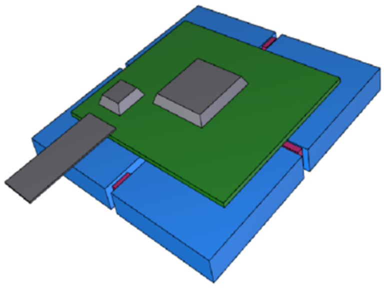
The forward spectrometer has additional but similar PID capabilities such as a RICH counter, a forward EMC, time of flight walls, and a forward muon detector.

In the next sections the dedicated PID systems will be explained in more detail.

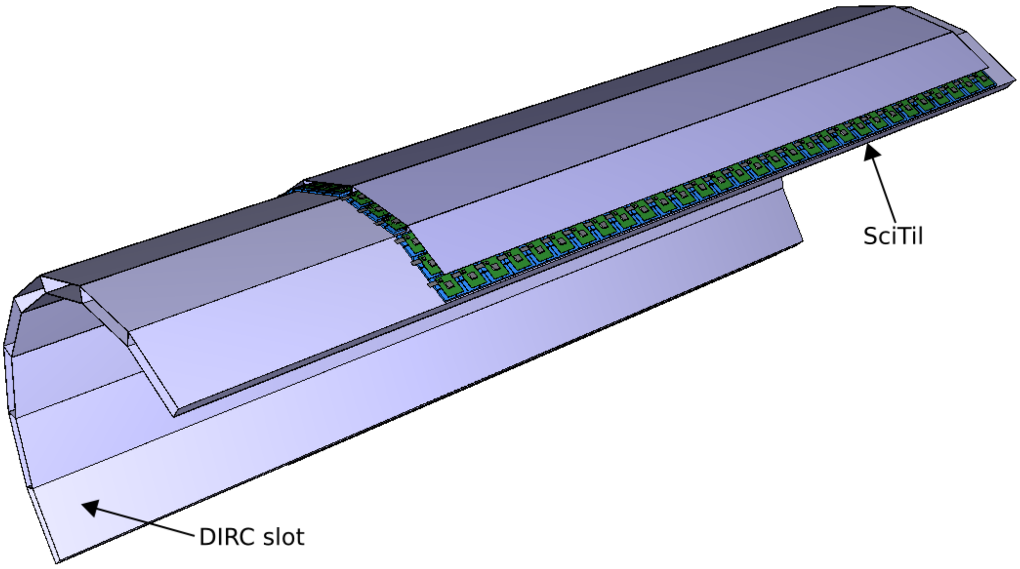
2.2 Time of flight



(a) scintillating tile



(b) SciTil quad module



(c) The SciTil sectors are connected to the slots of the Barrel DIRC.

Figure 3: Schematic view of the PANDA SciTil.

The SciTil [5] consists of plastic scintillator tiles as basic unit (Fig. 3a) with a size of $3 \times 3 \times 0.5\,\text{cm}^3$ each. Two silicon photo multipliers are attached to different edges of each tile to see as many photons as possible and to provide a relative timing. Four tiles share a common readout (e.g. ASIC chip) and form a *quad module* (Fig. 3b). One section contains 90 quad modules and 16 sections form the barrel TOF (Fig. 3c), for a total of 5760 scintillating tiles. Scintillating tiles are beneficial because they keep the material budget in front of the EMC small and yield about 100 detected photons per tile. A first discriminator threshold provides excellent timing by triggering on the first arriving photon. A second larger threshold distinguishes the event from noise counts. The time resolution of the SciTil can therefore be in the order of 100 ps.

The SciTil serves several purposes. It is a fast and reliable timing detector helping in the global event building of the triggerless PANDA experiment with an average interaction rate of 20 MHz. The PID capabilities of time of flight measurements can be used to identify particles with momenta below 1 GeV/c via relative timing. Other applications are the detection of photon conversion within the DIRC and provision of track seeds for the central trackers.

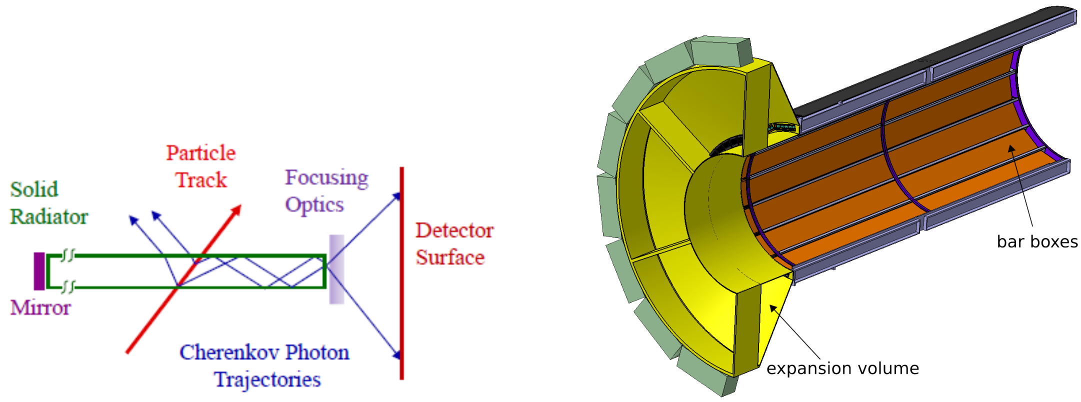
2.3 DIRC Detectors

The DIRC principle is the use of a solid radiator as a light guide (e.g. synthetic fused silica), where Cherenkov photons propagate to the readout end via total internal reflection. Figure 4a illustrates the concept. The main advantage of the detector is its compactness, as the total radial thickness, including the radiator, is less than 5 cm. The Cherenkov image is detected in an expansion region outside the detector acceptance. The first and so far only DIRC detector was succesfully operated in the BaBar experiment [6] as a barrel around the interaction point. At PANDA two implementations of DIRC counters can be found in the barrel region and in the forward endcap.

Barrel DIRC

The PANDA Barrel DIRC (Fig. 4b) is based on the BaBar DIRC with several improvements, such as focusing optics and fast photon timing [7]. The barrel has a radius of 47.6 cm and 80 radiator bars with a length of 250 cm and a cross-section of $1.7\,\text{cm}\times3.3\,\text{cm}$ in the baseline design. Five bars form one barrel section. Mirrors are attached to the bar in the downstream direction to reflect the photons towards the readout at the opposite end, where they are coupled out and focused via lenses into an expansion volume. This volume has a depth of 30 cm and is filled with mineral oil. Micro-channel plate photomultiplier tubes (MCP-PMT) are attached to the backsite of the volume with a pixel size of 6.5 mm and about 15,000 - 20,000 readout channels in total. For the PID process two spatial coordinates and a hit time per detected photon are measured. With these 3D-patterns, PID likelihoods for different particle hypothesises are calculated. The expected performance of the Barrel DIRC is a single photon Cherenkov angle resolution of about 10 mrad and at least 20 detected photons per track for all track angles, providing at least 3σ pion/kaon separation up to 3.5 GeV/c momentum.

Currently several design options are under investigation. A single wide plate per section instead of five narrow bars would significantly reduce the overall cost of the DIRC. Separate expansion volumes for each section, made of synthetic fused silica, would be simpler to operate and have better optical properties than an oil-filled tank. In addition there are investigations to use mirrors instead of lenses to focus the photons.



(a) (b)

Figure 4: (a) The DIRC principle on which (b) the Barrel DIRC (schematic view) is based on.

Disk DIRC

The forward endcap Disk DIRC is a novel device [8]. It consists of an octagonal disk, made of synthetic fused silica, with a diameter of 2 m. It is centered around the beam axis and divided into four optically independent segments (Fig. 5a). Cherenkov photons are totally internally reflected to the rim of the segments, where, behind dichroic mirrors for dispersion mitigation, they are collected by focusing light guide elements (see Fig. 5b). These elements have a reflecting curved surface and a readout surface, to which either SiPMs or MCP-PMTs are attached, depending on the final design.

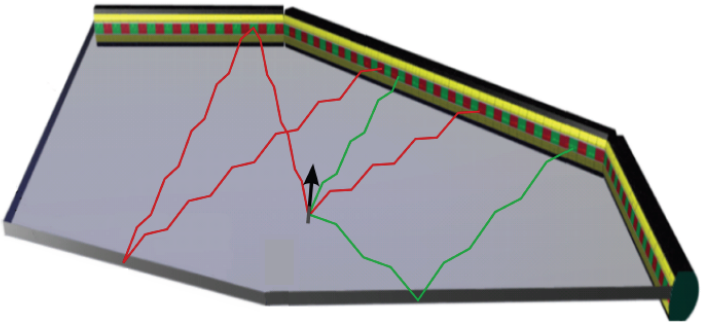
Challenges

The DIRC principle is a simple concept, but it is a challenging task to realize it. Photons experience a high number of total internal reflections, so efficient photon transportation requires high quality radiator surfaces, with a roughness of 10 - 20 Å. In addition a very good squareness is needed to keep the angle information of the propagated photon. These requirements make radiator polishing difficult and expensive, and few vendors worldwide are able to manufacture products with the desired quality. Currently these vendors are being identified and prototype samples are ordered and tested in particle beams.

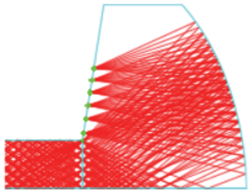
Another challenge are the high demands on the photo sensor. It has to be sensitive to single photons with a high detection efficiency, requires a low dark count rate, and should give a time resolution better than 100 ps. It has to operate in the 1 Tesla field of the PANDA solenoid and provide a photo cathode lifetime of at least 5 C/cm^2. Recent developments show a significantly increased lifetime for certain MCP-PMTs, which make them promising devices for the PANDA DIRC readout plane [9].

3. Summary and Outlook

Novel DIRC detectors play a crucial role in particle identification at the PANDA experiment. The design of the succesful BaBar DIRC is improved with the addition of focusing optics and fast



(a) Tilted view of a Disk DIRC quarter segment.



(b) A focusing light guide element. The disk is attached to the left side.

Figure 5: Schematic views of Disk DIRC components.

photon timing, and additional design improvements, such as radiator plates and compact expansion volumes, are being studied. A time of flight system, based on scintillating tiles and SiPM readout, is capable of identifying low momentum charged particles and plays an important role in the PANDA event building.

Both the DIRC detectors and the SciTil are currently in the final stages of the detector R&D. Construction of PANDA starts in 2015 with a preassembly at the research center in Jülich, Germany. The installation at FAIR is scheduled to start in 2017 and commissioning with beams in 2018.

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